

DESIGN STUDY OF AN ELECTRONIC LANDING DISPLAY FOR
STOL AIRCRAFT

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16. Abstract The design of landing display devices for STOL aircraft was investigated on the basis of information presentation and information content. A proposal is made for a contact analog landing display, which includes the perspective representation of mean flight path, information about actual flight status, predisplay of flight path coordinates, and boundary values for flight parameters. An approach procedure using the improved display is described.			
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DESIGN STUDY OF AN ELECTRONIC LANDING DISPLAY FOR STOL AIRCRAFT

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1. Basic Design Concept of Electronic Landing Displays for STOL Aircraft

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The excessive traffic at air lane nodes around airports and the requirement for short total travel times on short-range flights have resulted in the design of STOL aircraft, which have received considerable attention to date.

Aerodynamically supported aircraft must operate in the region of high lift coefficients and low horizontal speeds while making steep approaches and short landings. These result in the impairment of flight characteristics, manifested, among other things, in low control-surface efficiencies with simultaneously increased sensitivity to gusts.

Various avionics manufacturers are therefore working on the development of a new generation of highly complex automatic flight control systems that are meant to guarantee uninterrupted operation even in extreme weather minima [1].

For reasons of reliability and for the sake of system optimization in terms of the characteristic capabilities of man and machine, the pilot must possess full authority over his aircraft during every phase of flight. This means, on the one hand, that he be relieved of as many tasks as possible through automation;

* Numbers in the margin indicate pagination in the foreign text.

on the other hand, it must be guaranteed that the pilot is informed, completely and at the proper time, regarding the course followed by all processes so that he can switch over and continue with manual flight at any time.

A display suited to this task must thus provide the following 5 characteristics:

1. easily interpretable monitoring display for the automatic landing equipment;
2. suitable display for a manual landing in extreme weather minima.

If we proceed from the conventional principle of presenting individual flight variables and desired values separately with a mechanical display for each, we do not obtain satisfactory results, even when modern technologies, e.g. an electronic display, are employed, if the individual quantities are merely shown next to one another on a screen with various scales and indicators.

The task of designing a new type of display thus consists of eliminating the shortcomings of the cumbersome presentation of individual variables, involving a great interpretive effort, with an explicit, complex total presentation. At the present state of the art in electronic displays, it must be possible to present various quantities belonging to a group of data in such a manner that only a minimum of interpretation is necessary without a loss in information content. It is conceivable, for example, that scaling be inherent in the quantities themselves, via light intensity and color coding.

2. Requirements To Be Placed on Future Electronic Display Systems /6 for STOL Aircraft

In the following, information content and information presentation are treated as two different problem areas; we keep in mind throughout that information content and the mode of presentation often form a very intermeshed unit. The requirements broken down in this manner are particularly tailored to a head-down landing display.

2.1. General Requirements for a Landing Display

The basic requirement for a flight instrumentation system calls for the continuous presentation of data important for a particular phase of flight at a fixed location on the instrument panel, in an unchanging mode of presentation.

Display should be double so that either of the two pilots can operate the aircraft independently [2].

The symbols used in such a display must make the perception and mental processing of the presented information as easy as possible.

2.2. Information Content

The basic question concerning the information content of a landing display is: What should be displayed to the pilot so that he can execute a safe landing with an STOL aircraft? /7

Although the information content of an STOL landing display may vary with the particular information requirements of various aircraft configurations, a list of basic data can be compiled which will be of equal usefulness for all STOL aircraft types. (Table 1).

TABLE 1. LIST OF CRITICAL INFORMATION FOR STOL LANDING
APPROACH [3]

Attitude	Guidance	Speed
Roll	Glide slope deviation	Airspeed
Pitch	Course deviation	Vertical speed
Heading	Range	Ground speed
	Altitude	

2.3. Presentation

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The mode of presentation of data on various displays can be classified on the basis of the following categories:

- a) presentation of individual data
- b) presentation of combined data
- c) mixed presentation (presentation of individual data and combined data).

2.3.1. Presentation of Individual Data

The presentation of a single quantity is characterized by three primary factors:

- a) nature and movement of the symbol
- b) associations which are triggered by the mode of presentation
- c) sensitivity of indication and its scale range.

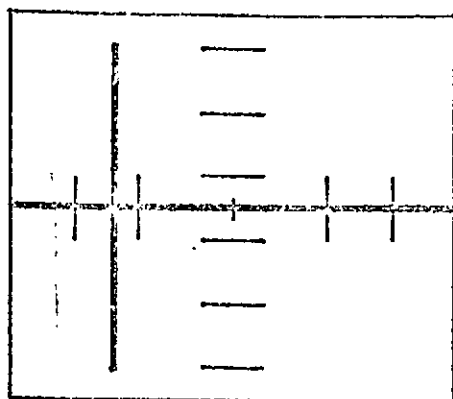
Symbol size and shape seem to be of secondary importance, as are the caligraphy of alphanumeric symbols and markings, color coding, contrast and brightness [4].

The nature and motion of a symbol can be presented both in abstract and in realistic form. Abstract presentation of a symbol and its motion is generally characterized by rotating pointers or dials or by longitudinal scales or markings which move linearly. This mode of representation originally came from conventional /9 electromechanical indicating methods and is not suitable for making use of the real advantages of up-to-date electronic display technology. In the latter case it is of course possible to present the type and motion of a symbol in considerably more complex form so as to produce a realistic impression of the immediate flight situation. Examples of abstract and realistic presentations of individual data are given in Fig. 1.

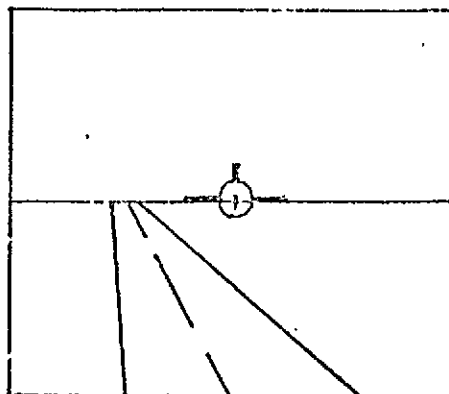
One can see that realistic presentation can even be used to integrate further data.

The associations which are triggered by a mode of presentation are closely related to the personal experience which a pilot has accumulated during the course of his training. On the one hand, their character is determined by continual work with conventional instrumentation; on the other hand, day-to-day contact with the real environment represents a good basis for the cognitive transfer of graphic information (cf. 2.3.3). The following example should contribute to clarification of the above:

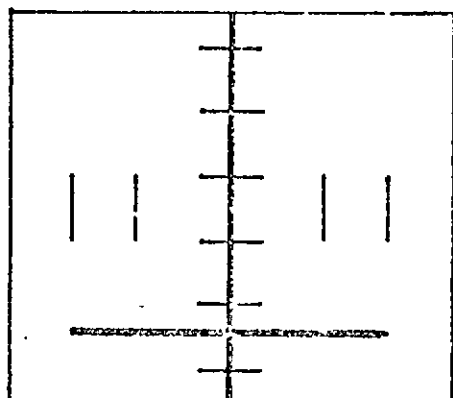
On conventional instruments, altitude is usually represented with a circular scale and several pointers rotating in the clockwise direction. An experienced pilot can make this reading with a relatively small percentage of misinterpretation on the basis of his training. If a longitudinal field scale which shows values that increase from bottom to top is used, however, rough /11



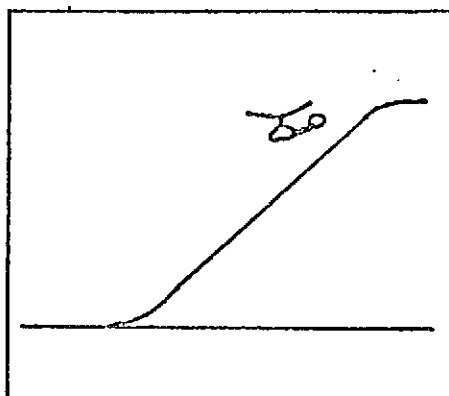
1.1.



1.2.



1.3.



1.4.

Fig. 1. Abstract and realistic presentations of individual data. Abstract (Fig. 1.1) and realistic (Fig. 1.2) presentations of horizontal deviation from a desired flight path; abstract (Fig. 1.3) and realistic (Fig. 1.4) presentation of vertical deviation from a desired flight path.

interpretation is found to be easier, since one can immediately associate this presentation with certain experiences from the real world.

On the other hand, the advantage of this longitudinal field display lies more in the increased read-off speed; it hardly

reduces the burden on the pilot when he must make exact altitude readings.

Two concepts, "inside-out" and "outside-in," have become common in the technical literature; these provide an expression of conscious adaptation of the mode of presentation to experience with one's environment.

In the "inside-out" concept, relative movements are shown to the pilot as they could be observed from the cockpit. This means that all symbols for the environment which is represented move relative to a fixed aircraft symbol and are opposite to the aircraft's actual motion (cf. Fig. 1.2).

In the "outside-in" concept, on the other hand, relative movements are presented as they would be seen from a point outside the aircraft which is fixed relative to the ground. In this case, the aircraft symbol used for indication is capable of both translational and rotational motion, while the symbols for its surroundings remain fixed (cf. Fig. 1.4).

The requirements for indicating-sensitivity and scale range sometimes differ considerably for the various phases of landing approach. The glide phase, followed by flareout and touchdown, certainly requires a greater level of sensitivity on the part of attitude instrumentation than during initial approach.

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A similarly varying requirement applies to the breakdown of scales into areas, if we consider altitude and distance readings.

The restrictions on satisfying these requirements are generally determined by the size of the screen.

2.3.2. Presentation of Combined Data

Different data can be coupled by a computer in such a manner that it becomes possible to use a single symbol, produced by a symbol generator, for their presentation. The data can even be combined in the presentation itself in such a manner that a realistic, or rather graphic, impression is produced. We might speak of a presentation which is based upon the relationship, in terms of content, among several pieces of data.

The combination of data in realistic form can range from a simple combination of two individual data (e.g. quickened display [5]) to the complex combination of several data.

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The most realistic combination of all attitude and guidance data is provided by a stereoscopic, perspective picture of the optical environment. Since the optical environment of the aircraft remains invisible without aids under poor weather conditions, however, an artificially generated picture must be presented to the pilot.

2.3.3. Mixed Mode of Presentation

An artificially generated image of the real environment which makes possible space-time orientation relative to a reference system fixed with respect to the ground can be supplemented by the additional display of alphanumeric data. Because the pilot can maintain contact with the environment, this presentation of artificially generated visual conditions is called "contact analog" or "conalog."

"Qualitative and quantitative displays often exhibit equivalent advantages and disadvantages which oppose one another. The quantitative display permits any desired precision in the

presentation of data, but the flow of information from the display to the pilot is inhibited by the time-consuming process of reading off the information and converting it into an analogous graphic idea (cf. p. 5: cognitive transfer of graphic information), whereas the qualitative presentation of data does provide a rapid and comprehensive impression of complex relationships but often does not possess the necessary indicating accuracy" [6]. /14

2.3.4. Human Engineering Requirements To Be Placed on a Landing Display

Characteristics which are specific to man primarily determine the layout of a suitable display system [7].

The pilot has been incorporated into the control circuit shown in Fig. 2. Whether the advantages of an up-to-date flying system, costing much in money and engineering effort, can be fully utilized depends upon him.

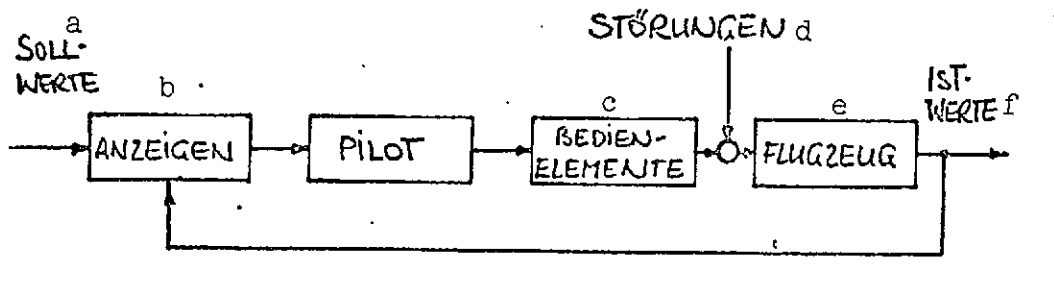


Fig. 2. Man as part of a control circuit [8].

- Key:
- a. Desired values
 - b. Instrument readings
 - c. Control
 - d. Interference
 - e. Aircraft
 - f. Actual values

It is apparent that the quality of the control circuit¹ is a function not only of the pilot's reaction speed and reaction reliability but also largely of data preparation and presentation. A suitable preparation and presentation of data are possible only /15 via the systematic researching of the human's characteristics: both his capabilities and his needs.

The control circuit assumed in Fig. 2 is used, with the formal methods of control engineering, to study human transfer behavior. Dey has indicated how controversial this approach is in [8]: "Although the control circuit has already been highly simplified, a large number of influencing parameters still remain in the study of a particular problem which are also decisive with regard to the permissibility of this simplified control circuit formulation. Important points include the knowledge which the pilot has of his task and the data concerning the task which he can obtain while executing it."

Among the parameters which may influence pilot transfer behavior, we can distinguish between external and internal parameters (see Table 2). The external parameters can usually be defined quite precisely; in the case of internal parameters, it must be observed that relationships exist not only between the internal but also with the outer parameters, and the former may be highly influenced by the latter. The internal influencing parameters are difficult to characterize qualitatively and quantitatively.

In theory, we must keep all influencing parameters constant /16 in order to be able to formally apply the theories and lines of reasoning of control engineering to the study of human transfer behavior.

¹ The quality of a control circuit is defined as mean square deviation in control.

TABLE 2. FACTORS WHICH INFLUENCE HUMAN TRANSFER BEHAVIOR [9]

Influencing factors	
External parameters	Internal parameters
Temperature	Psychological state (motivation, endurance, etc.)
Humidity	Physiological state
Lighting conditions	Random variability of transfer behavior
Annoyance due to noise	Learning behavior
Acceleration and vibration	Anthropogenic constants (extremities, muscular potentials)
Human-engineering structure of operating elements, their arrangement and layout	Stress and overtaxation
Layout of indicators/readings	Fatigue (monotony effect)
Psychological atmosphere of environment	
Characteristics of input signal	

The following basic human engineering requirements can be placed on an electronic landing display in the sense of a functional man-machine system that must exhibit the most effective distribution of tasks between the functions of the pilot and those of the automatic systems:

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1. In displaying landing data, an attempt should be made to obtain a three-dimensional presentation corresponding to natural viewing from the cockpit. In particular, this helps the pilot to interpret the display.

2. Data presented in combined form must be well structured so that overall comprehension is possible. The high information

density which results from the combining of data may not be taken so far, on the other hand, that the individual data from the integrated display system are no longer distinguishable in case of need. The use of different coding techniques [10] (dynamic and static illumination intensity coding, color, shape and symbol coding) is suitable for improving this structuring.

3. The display may not be laid out in such a manner that the pilot is forced to devote his entire attention to it. He must always be able to read additional monitoring instruments.

2.3.5. Requirements To Be Placed on a Landing Display Which Are Inherent to the System /18

1. The presentation of data must be free of distortion, particularly during landing approach, i.e. the picture of the approach situation which is shown must be true to the original in terms of distances and angles ("original" refers in this regard to the actual view from the cockpit).

2. The presentation of data must be true to scale, i.e. the picture of the approach situation which is shown must -- if viewed as a head-up display presentation -- coincide with the original.

3. A synthetic presentation of the external view should complete the overall picture of information during the entire landing phase, if possible [2, 11].

4. In addition to a perspective presentation of the desired flight path and the associated data concerning the instantaneous state of flight, the author considers presentation of the extension of the three-dimensional flight path (predisplay) to be particularly meaningful.

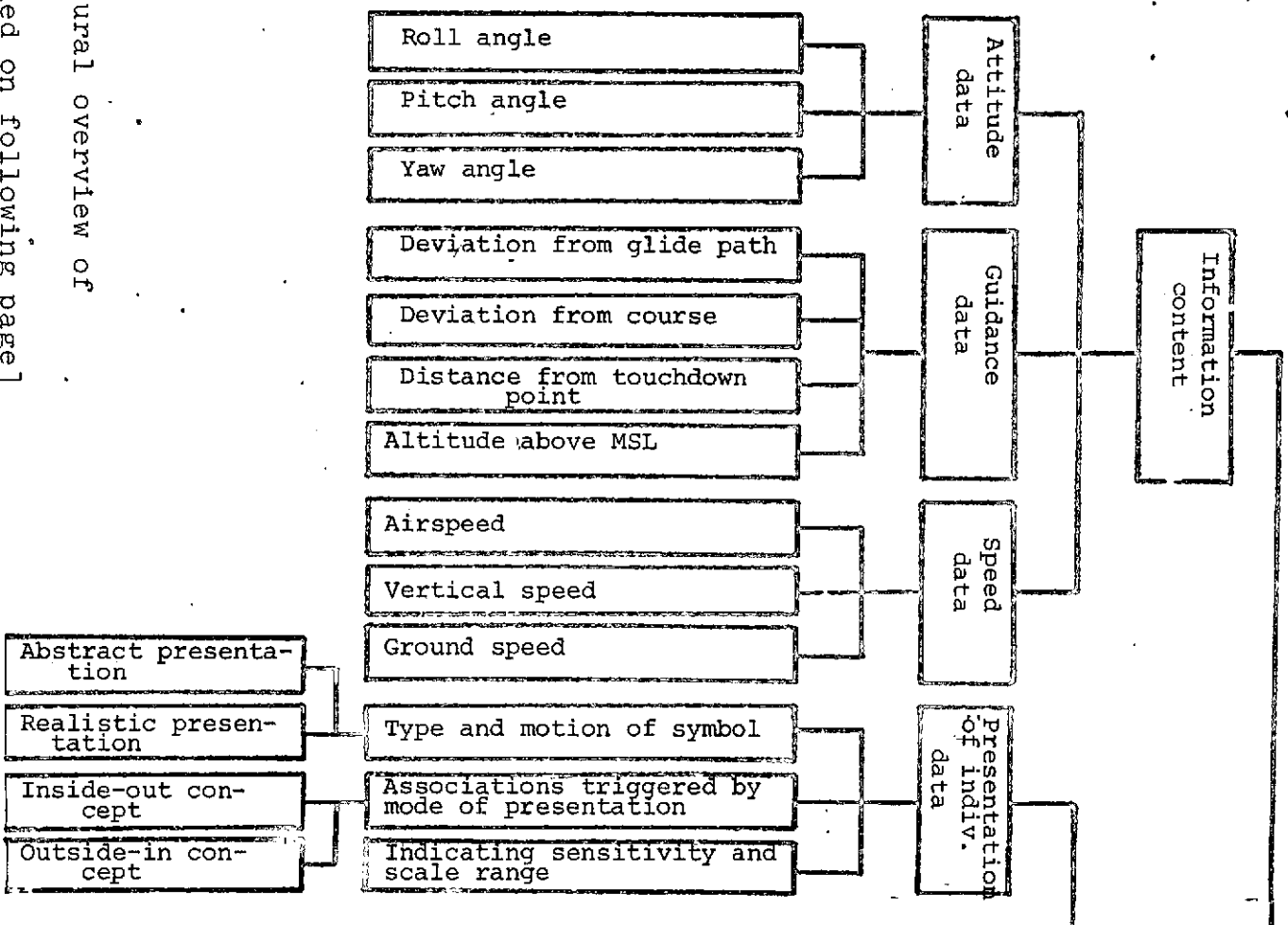


Fig. 3. Structural overview of requirements.

[Figure continued on following page]

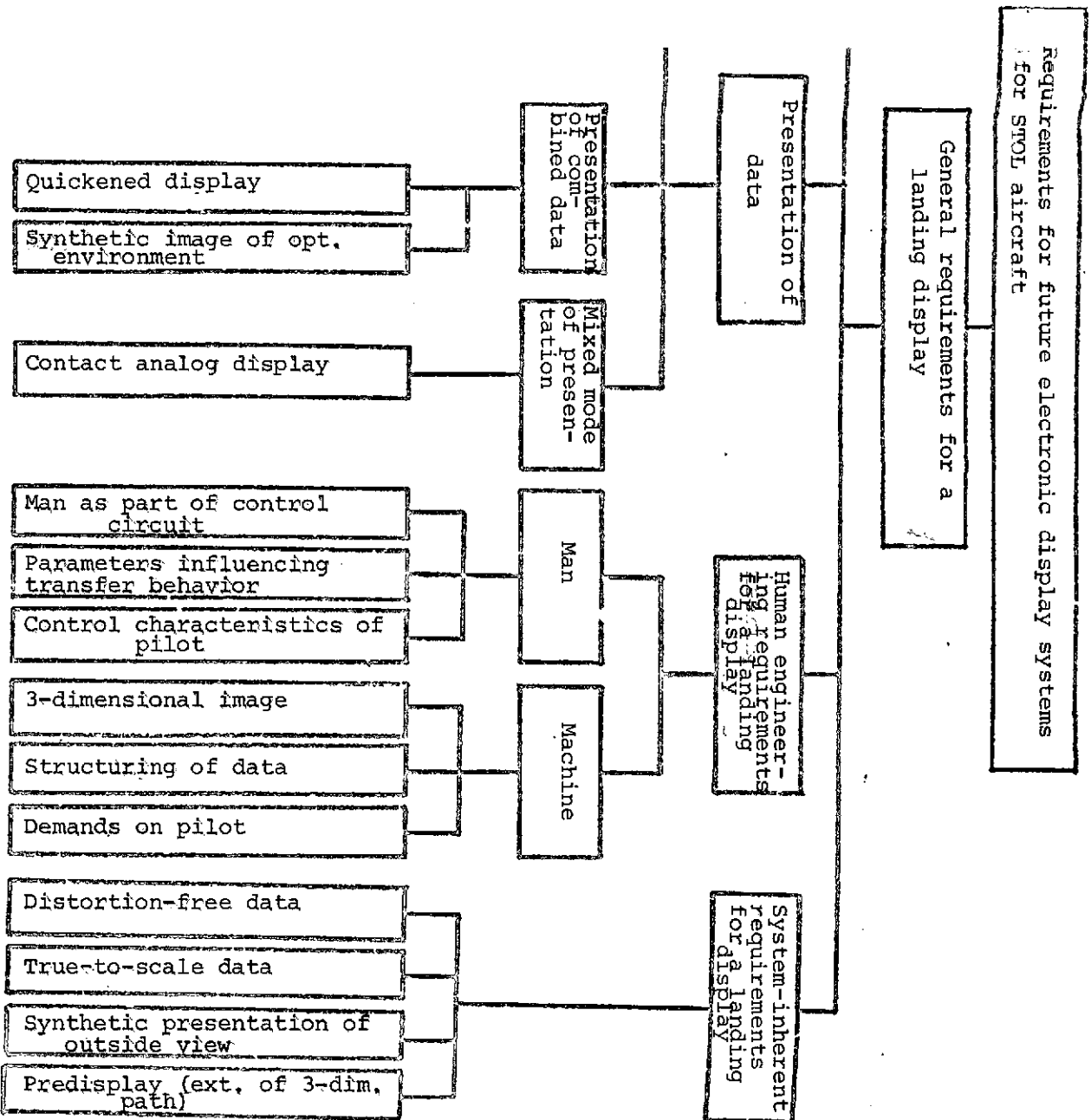


Fig. 3 (continued)

Predisplay should be presented with a vector symbol. The information content of the display must not decrease when the aircraft is in a neutral state (linear, uniform three-dimensional flight path). The predisplay must be able to present as many degrees of freedom as possible in graphic and realistic form. /19
An individual analog readoff of all data integrated into the display must be possible (cf. 3.1.3: Predisplay of Flight Path Coordinates).

5. An indication of the boundary on the safe operating range must be integrated. The range is assumed to be determined by an airborne computer from fixed parameters and those measured during landing approach. This indication of boundaries should make possible the easily interpreted monitoring of an automatic landing system which may be used (cf. 3.1.4: Indication of Flight Parameter Boundary Zone).

3. Proposed Design for an Electronic Contact Analog Landing Display for STOL Aircraft /21

3.1. Overall Design of the STOL Landing Display

The proposed design for a contact analog landing display (Fig. 4) is based on a perspective presentation of the vertical approach situation. Four different groups of data are displayed on a television tube scanned in a raster process² (CRT):

1. Perspective representation of desired flight path up to end of landing process (rollout from runway), representation of horizon with sharp silhouette below this line.

² The production of color images is made possible by vapor-depositing several fluorescent layers of different chemical compositions; these layers are scanned with an energy-modulated electron beam [12].

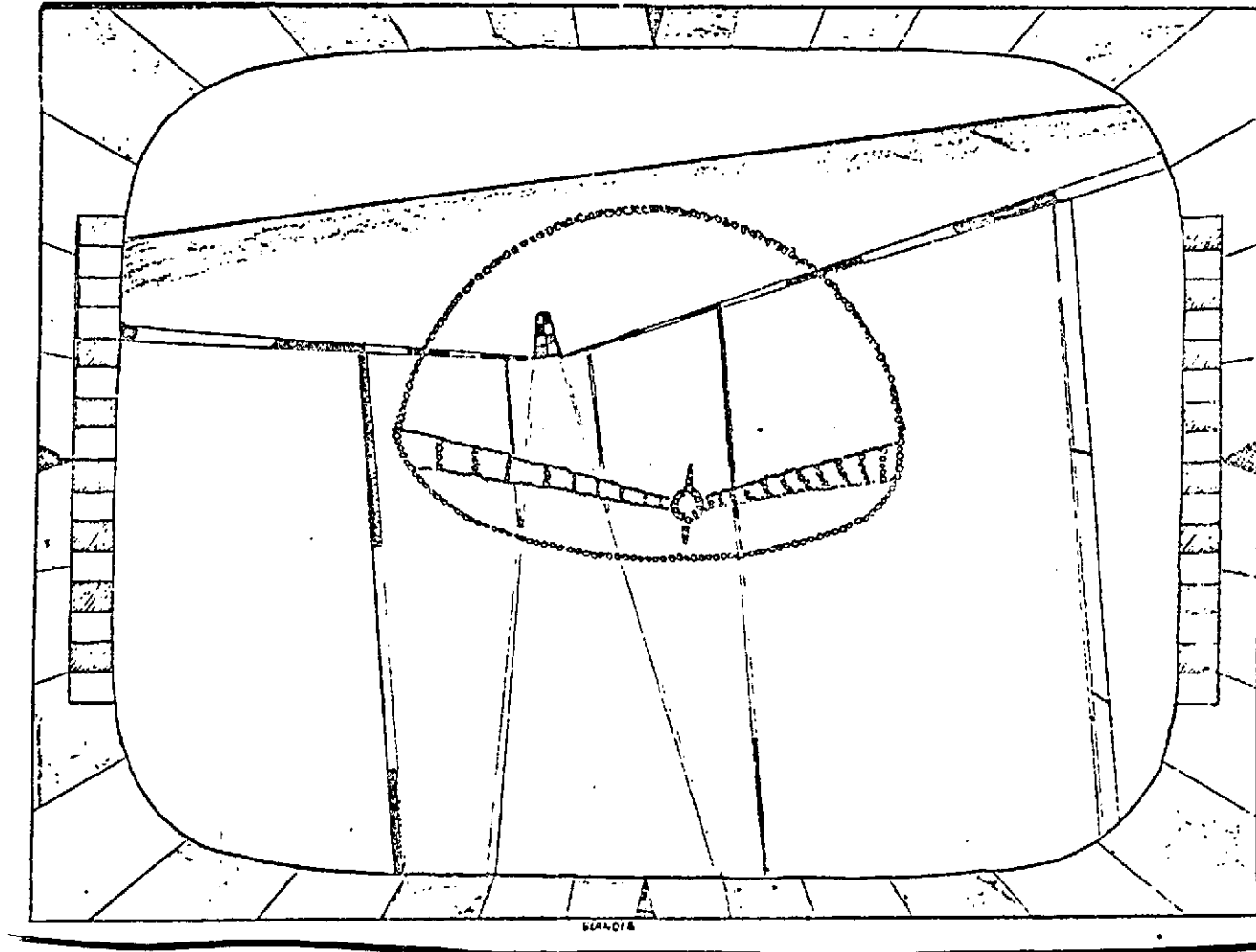


Fig. 4. Proposed design for a contact analog landing display (red lines are specially textured: ○○○○).

2. Data on instantaneous state of flight of landing STOL aircraft.

3. Predisplay of flight path coordinates (by extrapolation or fast computing model).

4. Boundary zone display (of attitude and speed parameters, plus c_{Lmax}) as automatic landing system monitoring readout.

These four groups of data are described separately below on 23 the basis of Fig. 4. These sections provide a description of the image and the proposed display.

3.1.1. Perspective Representation of Desired Flight Path

The desired flight path consists of the glide path and the runway itself. In Fig. 5, the auxiliary lines used in the display are shown in red.

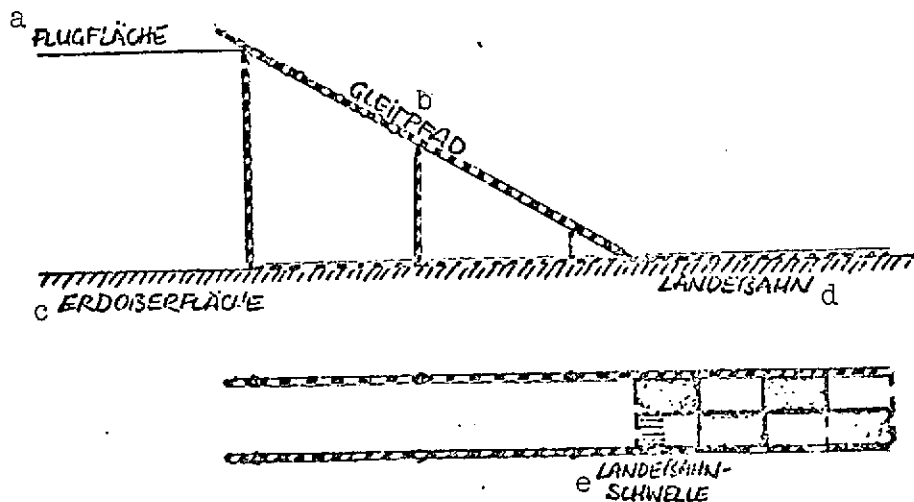


Fig. 5. Desired flight path and auxiliary lines used for presentation (see caption, Fig. 4).

Key: a. Flight level; b. Glide slope; c. Ground surface; d. Runway; e. Threshold of runway

The texture of the runway as presented permits a good estimate of distance to the end of the runway after touchdown. /24

In practice, it is not possible to fly the angular breaks in the desired flight path. An S-shaped approach path can easily be approximated through coordination with predisplay, however.

If we now compare Fig. 5 with Fig. 4, we can easily draw conclusions from the configuration regarding instantaneous attitude. The true-to-scale texture of all auxiliary lines will frequently permit a qualitative readoff of individual data here.

3.1.2. Data on Instantaneous Status of Flight

Instantaneous status of flight is shown in Fig. 4 by the relative position of the desired flight path in perspective. The frame of the screen and the boundary zone display (red circular line), always shown centrally, are used as a reference. The latter could be compared in this regard with an aircraft symbol fixed with respect to the screen, acting as a reference.

Occasional reference is made in the technical literature [13] to the idea that an inside-out display must necessarily have an aircraft symbol that is fixed relative to the screen to serve as a reference mark.

The characteristic properties of an aircraft symbol are satisfied without exception and obviously in a suitable manner even without this symbol in Fig. 4. The material in the central display area is thereby reduced. /25

As one can easily see, the state of flight shown in Fig. 4 is unequivocal and can be interpreted rapidly.

1. Attitude Data

a) Roll

The aircraft is in a right roll position (desired flight path with shadowed horizon is rotated about the theoretical intersection of the parallel runway boundary lines by an amount equal to the roll angle).

b) Pitch

The aircraft has a negative angle of attack (desired flight path and horizon lie above the center of the image by an amount corresponding to the pitch angle).

c) Yaw

The aircraft is in a right yaw position (desired flight path and horizon are located to the left of the image center by an amount corresponding to the yaw angle).

Small deviations from neutral attitude are noticed early as the result of asymmetry in the presentation.

If the aircraft is on its glide path, the angle of pitch or /26 angle of attack can be determined quantitatively with the 16-part scale along the right and left margins of the image. Corresponding considerations apply to the quantitative reading of angle of roll on the outer margin scale. The margin scale is drawn on a frame panel.

2. Guidance Data

a) Glide Slope

The aircraft is just under the glide plane (auxiliary lines for the glide plane are bent upward slightly).

b) Localizer

The aircraft is in the process of leaving the approach baseline toward the right (the extended runway center line intersects the lower margin of the screen to the left of center).

c) Altitude

The aircraft is located at the intersection of the flight level and the glide path at the height of the first vertical auxiliary lines and thus has a known altitude (the first vertical auxiliary line has already disappeared at the left margin, but is still visible at the right).

d) Distance from Touchdown Point or from End of Runway

A defined distance from the touchdown point is obtained from /27 the material discussed in item c). A good estimate of distance to the end of the runway is made possible during flareout, touchdown and rollout by the texture of the runway surface.

3. Speed Data

Speed on the glide path can be estimated roughly using the dynamic behavior of the presentation during approach (streamer pattern). An additional conventional airspeed indicator is probably indispensable.

3.1.3. Predisplay of Flight Path Coordinates

A vector symbol which has been derived from the form of a cone with a circular base is used to indicate upcoming flight path coordinates. In Fig. 6, the lines drawn in red correspond to the predisplay vector which is presented. The circular base of the cone is not used for representing the predisplay vector. Taking its place is the flight parameter boundary zone indicator described in the following section³. The point of the vector has been provided with an annular sight symbol for better differentiability (abstract aircraft symbol with outlined control surfaces).

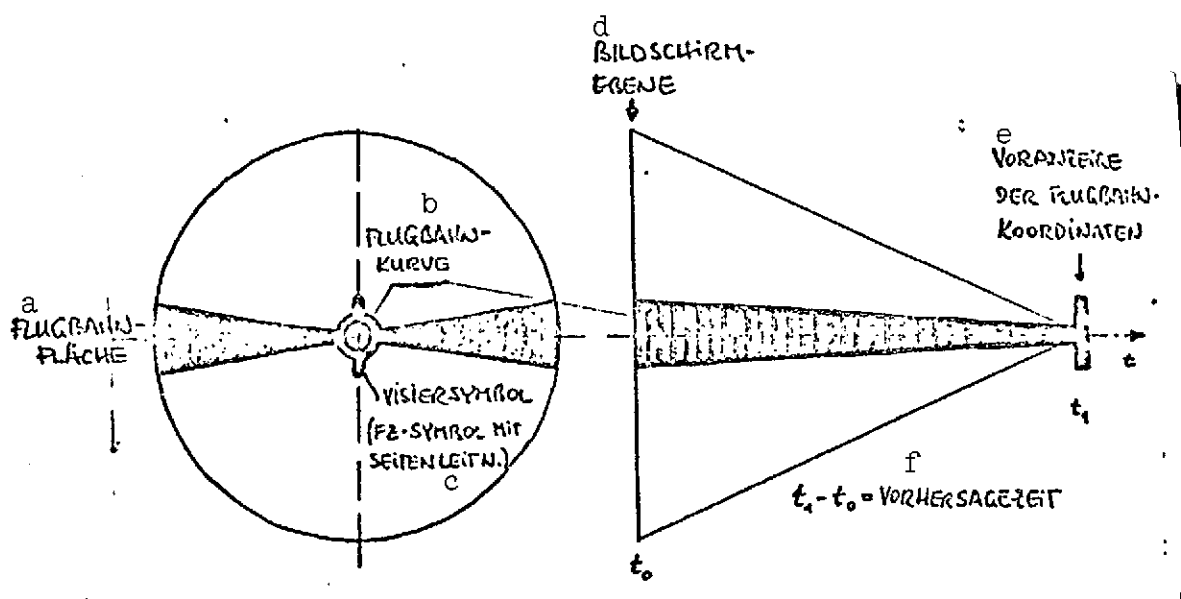


Fig. 6. Shape of predisplay vector (for unaccelerated flight: cone with circular base).

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- Key:
- a. Flight path surface
 - b. Flight path curve
 - c. Aiming symbol (aircraft symbol with rudder)
 - d. Plane of screen
 - e. Predisplay of flight path coordinates
 - f. Prediction time

³ The vector is used as the pointer of the boundary zone indicator. This indicator is used, among other things, to monitor the automatic landing system.

Looking back, we can now immediately read off the position of the aircraft for the near future: The aircraft will move linearly toward the lower right to the point indicated.

In the general case, the flight path curve of an aircraft can of course not be a straight line, since different accelerations affect the aircraft. But curved paths can also be indicated with the predisplay vector.

It can be seen from Fig. 6 that the flight path curve is itself represented only up to a point in the future (prediction of flight path coordinates at the location of the sight symbol). The actual vector symbol lies in the flight path surface normal to the vertical axis of the aircraft. Thus the curvature of the flight path curve can be determined from the representation of curvature in the flight path surface (cf. Fig. 6). In order to improve the recognizability of a curvature in the predisplay vector (three-dimensional curvature or spiral), an equidistant texture has been applied along the generatrices of the cone which are shown. Angles of roll can likewise be presented in the predisplay in conjunction with the stylized rudder on the sight symbol. /29

3.1.4. Indication of Flight Parameter Boundary Zone -- Indicator for Monitoring Automatic Landing System

The circular red base of the predisplay vector in Fig. 4 represents a multidimensional indication of boundary zones for attitude and speed parameters and c_{Lmax} values. The area within the circle bordered in red is an operating range here in which different flight parameters assume values at which safe aerodynamic maneuvering of the STOL aircraft is guaranteed. The tip of the predisplay vector (sight symbol), which performs the role of pointer in this indicator, may thus in no case leave the boundary zone, which is always closed, since a critical state of flight would otherwise occur (stalling, exceeding M_{crit} , side-slipping during bank, etc.).

The shape and size of the boundary zone are determined by the /30 factors listed below and are calculated with the aid of an airborne computer using a suitable data-coupling program.

TABLE 3. PARAMETERS FOR CALCULATING THE BOUNDARY ZONE

Boundary zone parameters		
Attitude	Speed	C_{Lmax}
Elevator angle	Fuel throttle setting	Aerodynamic design characteristics
Rudder angle	True airspeed (TAS)	Software for calculation of
Aileron deflection	Wind speed	C_{Lmax} , approximately optimized for real time
Maximum-lift flap position		
Landing gear position and load		
Trim		
Spoilers		

The following verbal examples should serve to explain the manner in which this indicator functions.

The boundary zone becomes larger with increasing aircraft maneuverability, and vice versa. Indication of the boundary zone disappears completely below speed v_{rot} (speed at which the aircraft can first assume an angle of attack during the takeoff phase). On the other hand, the boundary zone will narrowly circumscribe the sight symbol when critical Mach number M_{crit} is reached.

When an STOL aircraft is landing, the indication of such a /31 boundary zone is very useful for maneuverability. With the aircraft at a steep angle of attack, high sinking speed and low

ground speed, the pilot obtains not only the feeling of flight but also concrete information concerning the overall state of flight of his aircraft.

The flare situation prior to touchdown, quite critical for an STOL landing, can be flown through effortlessly with the boundary zone indicator and predisplay if, in addition, exact altimeter readings are fed in for zone calculation.

The interplay of various groups of data in the improved landing display is explained in the following section by means of a sequence of images during the landing process.

3.2. Landing Process with the Improved Display

The landing of an STOL aircraft can be subdivided into four sections (Fig. 7).

1. initial approach
2. intermediate approach
3. final approach
4. flare, touchdown, rollout.

In Fig. 8, a picture of the overall indicator image on the improved display is given for each of these landing segments. Fig. 8.1-8.6 correspond to the perspectives which one would observe from the locations labelled in Fig. 7. The indicator can be supplemented with a synthetic television picture serving as the background.

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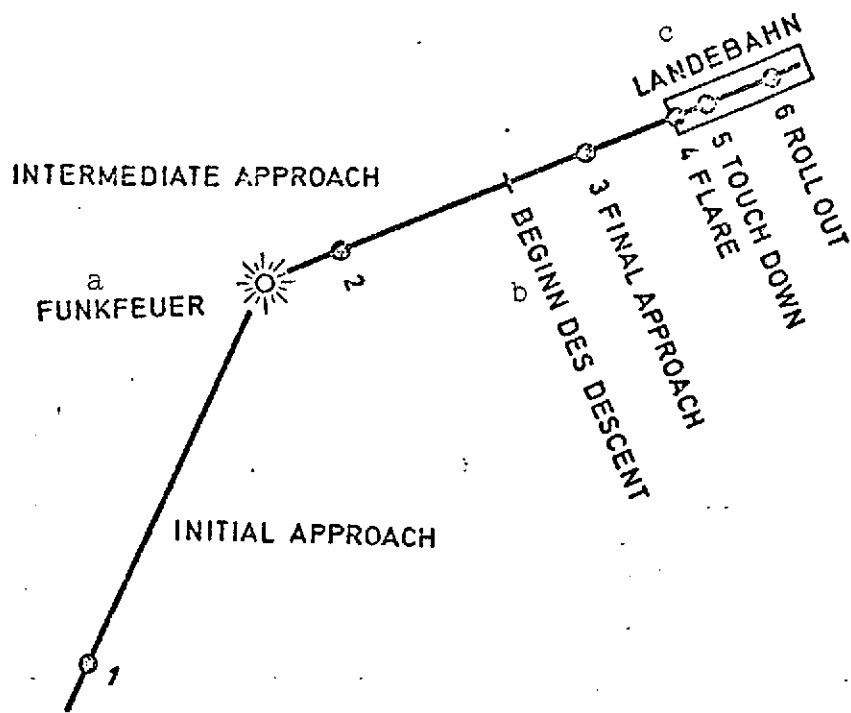
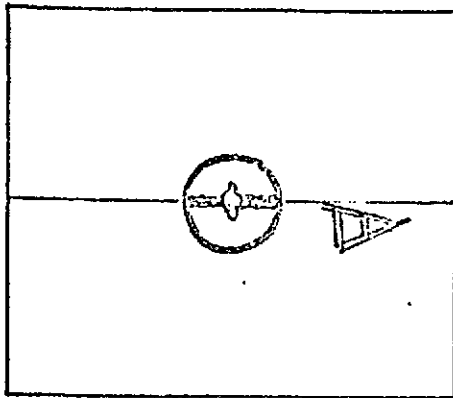
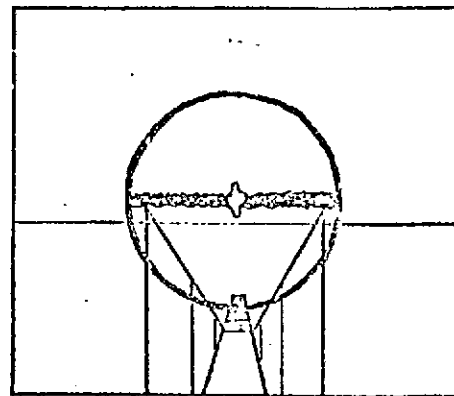


Fig. 7. Segments of an STOL aircraft landing.

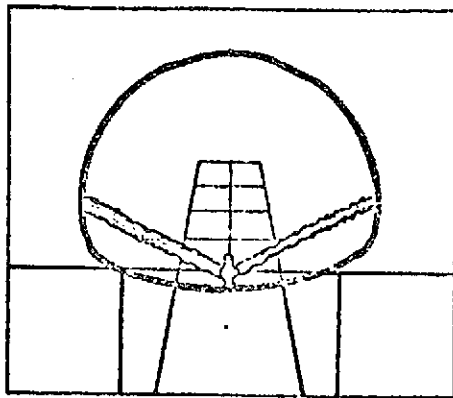
Key: a. Beacon
 b. Beginning of descent
 c. Runway



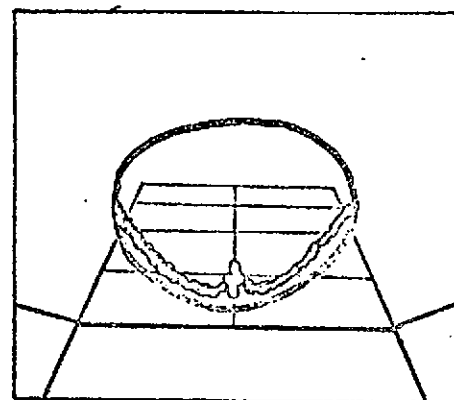
8.1.



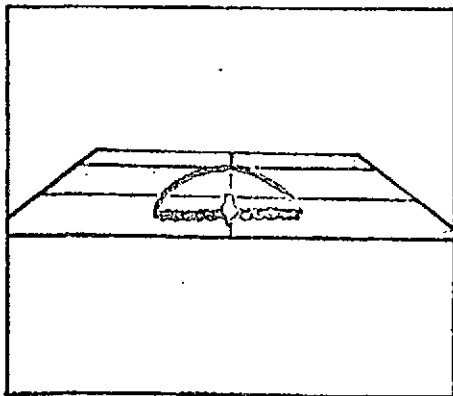
8.2.



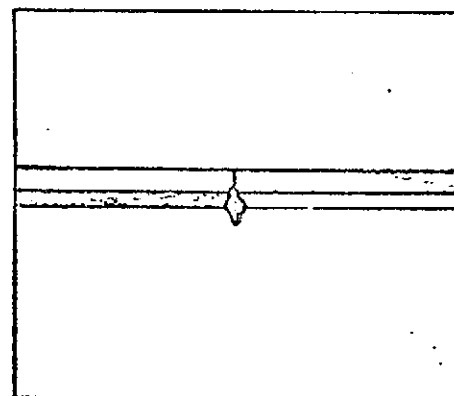
8.3.



8.4.



8.5.



8.6.

Fig. 8. Landing process with the improved display. Figs. 8.1-8.6 correspond to the perspectives seen from locations 1-6 in Fig. 7.

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